

Specification**ZOOM LENS AND IMAGING DEVICE**Technical Field

The present invention relates to a zoom lens and an imaging device equipped therewith, said zoom lens being suitable for the imaging optical system of digital input and output devices such as digital still cameras and digital video cameras on account of its compact size and variable power.

Background Art

Recent years have witnessed the wide diffusion of the imaging devices, such as digital still cameras, which are equipped with a solid-state imaging element. Digital still cameras are required to have an improved image quality as they become popular more than before. Particularly, those digital still cameras equipped with a solid-state imaging element having a large number of pixels need an imaging lens, especially a zoom lens, with good image-forming performance. They are also required to be small in size, and hence there is a strong demand for a small-size high-performance zoom lens. (See Japanese Patent No. 2750775 [Patent document 1]) On the other hand, attempts are being made to reduce the size of the zoom lens in the direction of an optical axis by bending the optical system with a

prism inserted between lenses. (See Japanese Patent Laid-open No. 248318-1996 [Patent document 2])

Insertion of a prism is a very effective way to reduce the lens diameter and length (or to reduce the overall lens size) for the optical system having the positive refracting power at the object side and the negative refracting power at the image side, in the case of conventional lens-shutter cameras for silver salt film. Unfortunately, it does not permit microlenses to fully exhibit their condensing performance because microlenses have the exit pupil near the image surface and are arranged in front of the solid-state imaging element. The problem is that the image brightness extremely varies in going from the image center to the image edge.

The object of miniaturization is not fully achieved in the optical system equipped with a solid-state imaging element (which is disclosed in the patent document 1), because the optical system employs a negative lens group as the last lens group which is limited in power. The object of miniaturization is not fully achieved either in the optical system disclosed in the patent document 2, which is designed to reduce the size in the direction of the optical axis by bending the optical axis with a prism inserted in the positive-negative-positive-positive zoom type, because the optical system employs a front lens and a reflecting member which are large in size.

Disclosure of the Invention

The present invention was completed to address the above-mentioned problems. Thus, the present invention is directed to a zoom lens and an imaging device equipped therewith. The zoom lens is composed of a plurality of lens groups arranged at variable intervals and hence is capable of power variation. Moreover, it contains a reflecting member to bend the optical axis, and its lens groups are characterized in that the last lens group (counted from the object side) consists of a negative lens group and a positive lens group, with an air layer interposed between them, which are sequentially arranged from the object side.

In addition, the present invention is directed to a zoom lens and an imaging device equipped therewith. The zoom lens is composed of a plurality of lens groups arranged at variable intervals and hence is capable of power variation. Moreover, it has the lens groups which are characterized in that the last lens group (counted from the object side) has a negative refracting power and consists of a negative lens group and a positive lens group, with an air layer interposed between them, which are sequentially arranged from the object side.

The advantage of the present invention is that the entire lens system can be miniaturized and the position of entrance pupil can be placed away from the image plane. This leads to size reduction and thickness reduction for

the zoom lens and the imaging device equipped therewith.

Brief Description of the Drawings

Fig. 1 is a diagram showing the lens arrangement of the zoom lens in the first example, which is adjusted to the end position of the short focal length.

Fig. 2 is a diagram showing the lens arrangement of the zoom lens in the second example, which is adjusted to the end position of the short focal length.

Fig. 3 is a diagram showing the lens arrangement of the zoom lens in the third example, which is adjusted to the end position of the short focal length.

Fig. 4 is a diagram showing the lens arrangement of the zoom lens in the fourth example, which is adjusted to the end position of the short focal length.

Figs. 5A to 5C are diagrams showing the aberrations which the zoom lens in the first example experiences when adjusted to the end position of the short focal length.

Figs. 6A to 6C are diagrams showing the aberrations which the zoom lens in the first example experiences when adjusted to a position of the intermediate focal length.

Figs. 7A to 7C are diagrams showing the aberrations which the zoom lens in the first example experiences when adjusted to the end position of the long focal length.

Figs. 8A to 8C are diagrams showing the aberrations which the zoom lens in the second example experiences when adjusted to the end position of the short focal length.

Figs. 9A to 9C are diagrams showing the aberrations which the zoom lens in the second example experiences when adjusted to a position of the intermediate focal length.

Figs. 10A to 10C are diagrams showing the aberrations which the zoom lens in the second example experiences when adjusted to the end position of the long focal length.

Figs. 11A to 11C are diagrams showing the aberrations which the zoom lens in the third example experiences when adjusted to the end position of the short focal length.

Figs. 12A to 12C are diagrams showing the aberrations which the zoom lens in the third example experiences when adjusted to a position of the intermediate focal length.

Figs. 13A to 13C are diagrams showing the aberrations which the zoom lens in the third example experiences when adjusted to the end position of the long focal length.

Figs. 14A to 14C are diagrams showing the aberrations which the zoom lens in the fourth example experiences when adjusted to the end position of the short focal length.

Figs. 15A to 15C are diagrams showing the aberrations which the zoom lens in the fourth example experiences when adjusted to a position of the intermediate focal length.

Figs. 16A to 16C are diagrams showing the aberrations which the zoom lens in the fourth example experiences when adjusted to the end position of the long focal length.

Best Mode for Carrying Out the Invention

The invention will be described in more detail with

reference to its preferred embodiments. The zoom lens demonstrated in the embodiments is a compact one intended for use with imaging devices such as video cameras and digital still cameras. The present invention covers a zoom lens of the type having a plurality of lens groups and varying in power in response to variation in intervals between the lens groups, which comprises a reflecting member to bend the optical axis passing through the lens groups and a last lens group (counted from the object side) which is composed of a negative lens group and a positive lens group, with an air layer interposed between them (arranged sequentially from the object side). The present invention also covers an imaging device equipped with an imaging element which converts the optical image formed by the zoom lens into electrical signals.

In the zoom lens according to the present embodiment, the lens groups should preferably be constructed such that the first lens group (counted from the object side) is stationary and contains said reflecting member. Moreover, in the zoom lens according to the present embodiment, the lens groups should preferably be constructed such that the last lens group (counted from the object side) has a negative refracting power.

In the zoom lens according to the present embodiment, the negative lens group of the last lens group should preferably satisfy the condition defined by the inequality (1) below.

$$0.9 < |f_a/f_w| < 1.25$$

where, f_a denotes the focal length of the negative lens group in the last lens group, and f_w denotes the focal length at its wide end.

The inequality (1) given above defines the focal length of the negative lens group in the last lens group. If the focal length is smaller than the lower limit of the inequality (1), then it would be difficult to correct the edge coma and the chromatic aberration of magnification. If the focal length is larger than the upper limit of the inequality (1), then the negative lens group has a weak power which prevents miniaturization.

The zoom lens according to the present invention may be composed of a plurality of lens groups alone, with the above-mentioned reflecting member omitted. Incidentally, in the case where a prism is used as the reflecting member to bend the optical axis, it is desirable to select one which is made of glass with a high refractive index.

(EXAMPLES)

A description is given below of the examples of the present invention. Fig. 1 is a diagram showing the lens arrangement of the zoom lens in the first example. The arrows in the figure represent the loci along which the lens groups move in going from the wide end position to the tele end position. The zoom lens in the first example consists of a first lens group GR1 (positive), a second

lens group GR2 (negative), a third lens group GR3 (positive), a fourth lens group GR4 (positive), and a fifth lens group GR5 (negative), which are arranged sequentially from the object side. The first lens group GR1 consists of a negative lens G1, a rectangular prism G2 to bend the optical axis through 90° , and a positive lens G3 having aspherical surfaces on both sides.

The second lens group GR2 consists of a negative lens G4, a negative lens G5, and a positive lens G6, which are cemented together. The third lens group GR3 is a positive lens G7 having aspherical surfaces on both sides. The fourth lens group GR4 consists of a positive lens G8 having an aspherical surface at the object side and a negative lens G9, which are cemented together. The fifth lens group GR5 consists of a negative lens G10 and a positive lens G11, which are cemented together, and a positive lens G12. Incidentally, "LPF" denotes a filter, "CG" denotes a cover glass, and "IMG" denotes the receiving surface of the imaging element.

Fig. 2 is a diagram showing the lens arrangement of the zoom lens in the second example. The arrows in the figure represent the loci along which the lens groups move in going from the wide end position to the tele end position. The zoom lens in the second example consists of a first lens group GR1 (positive), a second lens group GR2 (negative), a third lens group GR3 (positive), a fourth lens group GR4 (positive), and a fifth lens group GR5

(negative), which are arranged sequentially from the object side. The first lens group GR1 consists of a negative lens G1, a rectangular prism G2 to bend the optical axis through 90°, and a positive lens G3 having aspherical surfaces on both sides.

The second lens group GR2 consists of a negative lens G4, a negative lens G5, and a positive lens G6, which are cemented together. The third lens group GR3 is a positive lens G7 having aspherical surfaces on both sides. The fourth lens group GR4 consists of a positive lens G8 having aspherical surfaces on both sides and a negative lens G9. The fifth lens group G5 consists of a negative lens G10 and a positive lens G11. Incidentally, "LPF" denotes a filter, "CG" denotes a cover glass, and "IMG" denotes the receiving surface of the imaging element.

Fig. 3 is a diagram showing the lens arrangement of the zoom lens in the third example. The arrows in the figure represent the loci along which the lens groups move in going from the wide end position to the tele end position. The zoom lens in the third example consists of a first lens group GR1 (positive), a second lens group GR2 (negative), a third lens group GR3 (positive), a fourth lens group GR4 (positive), and a fifth lens group GR5 (negative), which are arranged sequentially from the object side. The first lens group GR1 consists of a negative lens G1, a rectangular prism G2 to bend the optical axis through 90°, and a positive lens G3 having aspherical surfaces on

both sides.

The second lens group GR2 consists of a negative lens G4, a negative lens G5, and a positive lens G6, which are cemented together. The third lens group GR3 is a positive lens G7 having aspherical surfaces on both sides. The fourth lens group GR4 consists of a positive lens G8 having an aspherical surface at the object side and a negative lens G9, which are cemented together. The fifth lens group GR5 consists of a negative lens G10 and a positive lens G11, which are cemented together, and a positive lens G12. Incidentally, "LPF" denotes a filter, "CG" denotes a cover glass, and "IMG" denotes the receiving surface of the imaging element.

Fig. 4 is a diagram showing the lens arrangement of the zoom lens in the fourth example. The arrows in the figure represent the loci along which the lens groups move in going from the wide end position to the tele end position. The zoom lens in the fourth example consists of a first lens group GR1 (positive), a second lens group GR2 (negative), a third lens group GR3 (positive), a fourth lens group GR4 (positive), and a fifth lens group GR5 (negative), which are arranged sequentially from the object side. The first lens group GR1 consists of a negative lens G1, a rectangular prism G2 to bend the optical axis through 90°, and a positive lens G3 having aspherical surfaces on both sides.

The second lens group GR2 consists of a negative lens

G4, a negative lens G5, and a positive lens G6, which are cemented together. The third lens group GR3 is a positive lens G7 having aspherical surfaces on both sides. The fourth lens group GR4 consists of a positive lens G8 having an aspherical surface at the object side and a negative lens G9, which are cemented together. The fifth lens group GR5 consists of a negative lens G10 and a positive lens G11, which are cemented together, and a positive lens G12 having an aspherical surface at the object side. Incidentally, "LPF" denotes a filter, "CG" denotes a cover glass, and "IMG" denotes the receiving surface of the imaging element.

Tables 1 to 4 below show the specifications of the zoom lenses in Examples 1 to 4.

TABLE 1

FNo. = 3.60 ~ 3.82 ~ 4.33

f = 6.88 ~ 11.75 ~ 20.13

 ω = 30.15 ~ 17.69 ~ 10.41

Surface No.	R	d	nd	νd
1:	24.314	0.650	1.92286	20.884
2:	11.460	1.706		
3:	INFINITY	10.400	1.84666	23.785
4:	INFINITY	0.300		
5:	13.444 (ASP)	2.041	1.76802	49.300
6:	-32.214 (ASP)	0.600 ~ 3.953 ~ 6.348		
7:	45.683	0.500	1.83500	42.984
8:	6.670	0.962		
9:	-8.756	0.450	1.83500	42.984
10:	8.338	1.100	1.92286	20.884
11:	77.391	6.248 ~ 2.894 ~ 0.500		
12:	13.396 (ASP)	1.342	1.80611	40.734
13:	-22.669 (ASP)	1.000		
14:	Diaphragm	6.143 ~ 4.137 ~ 2.002		
15:	9.726 (ASP)	2.058	1.58313	59.460
16:	-6.016	0.550	1.84666	23.785
17:	-10.574	1.500 ~ 3.506 ~ 5.641		
18:	-3257.375	0.500	1.84666	23.785
19:	4.886	1.200	1.49700	81.608
20:	7.983	4.929		
21:	12.428	1.710	1.84666	23.785
22:	-102.036	2.200		
23:	INFINITY	1.700	1.51680	64.198
24:	INFINITY	1.120		
25:	INFINITY	0.500	1.51680	64.198
26:	INFINITY			

Surface No.	ϵ	A^4	A^6	A^8	A^{10}
5	1	-0.840224E-04	0.108789E-05	-0.274452E-07	-0.276900E-08
6	1	-0.411280E-04	0.235427E-05	-0.102904E-06	-0.104317E-08
12	1	-0.102097E-03	-0.939322E-05	0.172600E-05	-0.985871E-07
13	1	0.410092E-04	0.430239E-05	-0.207652E-06	-0.229518E-09
15	1	-0.353645E-03	0.199877E-04	-0.290779E-05	0.160608E-06

TABLE 2

FNo. = 3.60 ~ 3.91 ~ 4.56

f = 6.91 ~ 11.60 ~ 19.52

 ω = 29.96 ~ 17.97 ~ 10.74

Surface No.	R	d	nd	νd
1:	25.369	0.650	1.92286	20.884
2:	8.327	1.780		
3:	INFINITY	8.000	1.83500	42.984
4:	INFINITY	0.300		
5:	15.439 (ASP)	2.224	1.76802	49.300
6:	-19.755 (ASP)	0.500 ~ 4.375 ~ 7.141		
7:	17.289	0.500	1.83500	42.984
8:	7.267	1.092		
9:	-9.657	0.450	1.80420	46.503
10:	11.003	1.100	1.92286	20.884
11:	58.748	7.180 ~ 3.305 ~ 0.539		
12:	15.059 (ASP)	1.450	1.80611	40.734
13:	-55.971 (ASP)	1.000		
14:	Diaphragm	6.607 ~ 4.519 ~ 2.049		
15:	10.414 (ASP)	2.200	1.58313	59.460
16:	-8.132 (ASP)	0.383		
17:	-8.821	0.550	1.84666	23.785
18:	-16.182	2.324 ~ 4.412 ~ 6.892		
19:	-109.259	0.580	1.84666	23.785
20:	7.004	1.300		
21:	11.199	3.000	1.48749	70.441
22:	-14.147	5.500		
23:	INFINITY	1.700	1.51680	64.198
24:	INFINITY	1.120		
25:	INFINITY	0.500	1.51680	64.198
26:	INFINITY			

Surface No.	ϵ	A^4	A^6	A^8	A^{10}
5	1	-0.927469E-04	0.261903E-05	-0.132821E-06	0.309627E-08
6	1	-0.675780E-04	0.360001E-05	-0.178921E-06	0.415484E-08
12	1	-0.621787E-05	0.998207E-05	-0.792395E-06	0.440588E-07
13	1	0.124983E-03	0.925746E-05	-0.600970E-06	0.377290E-07
15	1	-0.223643E-03	-0.514160E-05	-0.521675E-06	-0.135921E-06
16	1	0.129992E-03	0.119792E-05	-0.172572E-05	-0.531183E-07

TABLE 3

FNo. = 3.60 ~ 3.80 ~ 4.36

f = 6.88 ~ 11.76 ~ 19.78

 ω = 30.17 ~ 17.74 ~ 10.58

Surface No.	R	d	nd	νd
1:	29.596	0.800	1.92286	20.884
2:	11.833	1.550		
3:	INFINITY	10.340	1.84666	23.785
4:	INFINITY	0.300		
5:	13.176 (ASP)	2.001	1.76802	49.300
6:	-32.361 (ASP)	0.600 ~ 4.048 ~ 6.307		
7:	39.783	0.500	1.83500	42.984
8:	7.129	0.891		
9:	-9.370	0.450	1.83500	42.984
10:	6.699	1.135	1.92286	20.884
11:	29.165	6.207 ~ 2.759 ~ 0.500		
12:	11.505 (ASP)	1.555	1.58313	59.460
13:	-10.840 (ASP)	1.000		
14:	Diaphragm	7.415 ~ 4.719 ~ 2.048		
15:	10.125 (ASP)	1.881	1.58313	59.460
16:	-8.255	0.540	1.84666	23.785
17:	-14.464	1.513 ~ 4.209 ~ 6.880		
18:	-103.537	0.500	1.84666	23.785
19:	4.674	1.253	1.48749	70.441
20:	8.681	2.908		
21:	11.886	1.597	1.84666	23.785
22:	-76.923	2.553		
23:	INFINITY	1.700	1.51680	64.198
24:	INFINITY	1.120		
25:	INFINITY	0.500	1.51680	64.198
26:	INFINITY			

Surface No.	ϵ	A ⁴	A ⁶	A ⁸	A ¹⁰
5	1	-0.113945E-03	0.180324E-05	0.387819E-07	-0.501495E-08
6	1	-0.747724E-04	0.483239E-05	-0.123687E-06	-0.191289E-08
12	1	-0.624370E-03	-0.916356E-04	0.895972E-05	-0.104621E-05
13	1	-0.267344E-03	-0.588310E-04	0.421433E-05	-0.697018E-06
15	1	-0.319893E-03	0.408341E-04	-0.678945E-05	0.378621E-06

TABLE 4

FNo. = 3.60 ~ 3.81 ~ 4.25

f = 6.83 ~ 11.68 ~ 19.54

 ω = 30.24 ~ 17.80 ~ 10.72

Surface No.	R	d	nd	νd
1:	26.824	0.800	1.92286	20.884
2:	10.610	1.692		
3:	INFINITY	10.040	1.83500	42.984
4:	INFINITY	0.300		
5:	12.806 (ASP)	2.247	1.69350	53.201
6:	-22.355 (ASP)	0.600 ~ 4.166 ~ 6.649		
7:	160.098	0.500	1.83500	42.984
8:	7.112	0.863		
9:	-10.046	0.450	1.83500	42.984
10:	8.690	1.123	1.92286	20.884
11:	167.317	6.549 ~ 2.982 ~ 0.500		
12:	10.470 (ASP)	1.468	1.69350	53.201
13:	-20.925 (ASP)	1.000		
14:	Diaphragm	6.676 ~ 4.289 ~ 2.016		
15:	10.551 (ASP)	1.778	1.58313	59.460
16:	-8.678	0.500	1.84666	23.785
17:	-15.262	1.632 ~ 4.019 ~ 6.291		
18:	290.056	0.500	1.84666	23.785
19:	4.274	1.616	1.48749	70.441
20:	12.116	3.300		
21:	9.938 (ASP)	1.500	1.82121	24.060
22:	42.003	2.250		
23:	INFINITY	1.000	1.51680	64.198
24:	INFINITY	1.120		
25:	INFINITY	0.500	1.51680	64.198
26:	INFINITY			

Surface No.	ϵ	A^4	A^6	A^8	A^{10}
5	1	-0.568516E-04	0.306406E-05	-0.204971E-06	0.288123E-08
6	1	0.344007E-04	0.318929E-05	-0.244248E-06	0.430250E-08
12	1	-0.221211E-04	0.203278E-04	-0.141299E-05	0.205676E-06
13	1	0.258952E-03	0.279247E-04	-0.237181E-05	0.270745E-06
15	1	-0.229359E-03	0.645370E-05	-0.122235E-05	0.620922E-07
21	1	-0.546399E-04	0.123335E-05	0.268354E-06	-0.737017E-08

Symbols in the tables above mean as follows.

F No. : F number

F : focal length

ω : half field angle

R : radius of curvature

d : distance from one lens surface to next

nd : refractive index for d-line

vd : Abbe's number

ASP : aspherical surface

The shape of the aspherical surface is defined by the formula below.

$$x = \frac{y^2 \cdot c^2}{1 + \sqrt{1 - \varepsilon \cdot y^2 \cdot c^2}} + \sum A^i \cdot Y^i$$

where,

x : distance from the vertex of the lens surface measured in the optical axis

y : height measured in the direction perpendicular to the optical axis

C : paraxial curvature measured at the lens vertex

ε : conic constant

A^i : the i^{th} aspherical constant

Table 5 below shows the value of f_a/f_w in the inequality (1) given above which is applicable to each of Examples 1 to 4.

Table 5

Inequality (1)	Example 1	Example 2	Example 3	Example 4
fa/fw	1.045	1.113	0.988	1.157

Figs. 5A to 16C show aberrations observed in Examples.

Figs. 5A to 5C are diagrams of aberrations in Example 1, with the zoom lens being adjusted to the end position of the short focal length.

Figs. 6A to 6C are diagrams of aberrations in Example 1, with the zoom lens being adjusted to a position of the intermediate focal length.

Figs. 7A to 7C are diagrams of aberrations in Example 1, with the zoom lens being adjusted to the end position of the long focal length.

Figs. 8A to 8C are diagrams of aberrations in Example 2, with the zoom lens being adjusted to the end position of the short focal length.

Figs. 9A to 9C are diagrams of aberrations in Example 2, with the zoom lens being adjusted to a position of the intermediate focal length.

Figs. 10A to 10C are diagrams of aberrations in Example 2, with the zoom lens being adjusted to the end position of the long focal length.

Figs. 11A to 11C are diagrams of aberrations in Example 3, with the zoom lens being adjusted to the end position of the short focal length.

Figs. 12A to 12C are diagrams of aberrations in Example 3, with the zoom lens being adjusted to a position of the intermediate focal length.

Figs. 13A to 13C are diagrams of aberrations in Example 3, with the zoom lens being adjusted to the end position of the long focal length.

Figs. 14A to 14C are diagrams of aberrations in Example 4, with the zoom lens being adjusted to the end position of the short focal length.

Figs. 15A to 15C are diagrams of aberrations in Example 4, with the zoom lens being adjusted to a position of the intermediate focal length.

Figs. 16A to 16C are diagrams of aberrations in Example 4, with the zoom lens being adjusted to the end position of the long focal length.

In the diagram showing the spherical aberration, the ordinate represents the ratio to the open F value and the abscissa represents the defocus, and the solid line, broken line, and chain line represent respectively spherical aberration due to d-line, c-line, and g-line. In the diagram showing the astigmatism, the ordinate represents the image height and the abscissa represents the focus, and the solid line and broken line represent respectively the sagittal image surface and the meridional image surface. In the diagram showing the distortion, the ordinate represents the image height and the abscissa represents the distortion (%).

The zoom lenses according to the first to fourth examples satisfy the inequality (1) as shown in Table 5. As shown in each diagram of aberration in the Example, each aberration with the zoom lense being adjusted to the wide

end position, the intermediate position (between the wide end position and the tele end position), and the tele end position is properly corrected.

The foregoing description is about some preferred embodiments of the disclosure of the invention and it is intended that the configurations and structures of all matter shown as preferred embodiments shall be interpreted as illustrative and not in a limiting sense.

Therefore, the present invention contributes to the improvement (in image forming performance) and miniaturization of the zoom lens to be used for video cameras and digital still cameras.

Industrial Applicability

The zoom lens pertaining to the present invention may be applicable not only to imaging devices such as digital still cameras and digital video cameras but also to other imaging devices to be built into mobile phones, personal computers, and PDA (personal digital assistance).

